U. S. NAVY EXPERIMENTAL DIVING UNIT
WASHINGTON NAVY YARD
WASHINGTON, D.C. 20390

MEMORANDUM REPORT
10 February 1967

EXPERIENCE WITH MINIMAL RECOMPRESSION, OXYGEN BREATHING TREATMENT OF DECOMPRESSION SICKNESS AND AIR EMBOLISM

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A. PURPOSE

1. The purpose of this memorandum is to review the records to 1 January 1967 concerning experience with the use of the Minimal Recompression, Oxygen Breathing Treatment (Table 5 and Table 6) of decompression sickness and air embolism as reported to the Experimental Diving Unit, and to recommend that the method of use of this treatment be standardized and promulgated in a fleet Instruction as an approved, alternate procedure for the treatment of those diving accidents.

B. SUMMARY

1. 123 cases of decompression sickness have been treated by this new method of recompression to shallow depth while breathing 100% oxygen. 105 patients were completely relieved of all defects after one treatment, 9 required only one additional treatment, and 1 was completely relieved after a third treatment. These totals represent an 85.4% initial and a 93.5% overall success rate. The 8 remaining patients received less than complete relief of all symptoms but 7 received substantial benefit from the treatment.

2. The Commanding Officer, Submarine Medical Center, has developed a modification of this method for the treatment of traumatic air embolism resulting from submarine escape training. With this method the patient is initially compressed to 165 feet on air, then brought back to 60 feet and given hyperbaric oxygenation from that depth to the surface. Eighteen cases of air embolism have been treated, 6 following diving operations and 12 following submarine escape training. 17 patients received complete relief with the treatment given, 1 had minimal weakness and numbness of his right shoulder 24 hours after completion of treatment. 3 recurrences were noted in the submarine trainees, all successfully handled by a retreatment on Table 4 in one early case or by recurrence treatment on Table 6 in two cases.

3. The method of treatment employed in Table 5 and 6 has been used for treatment of persistent dysbarism in 5 aviation personnel. Beneficial results in all 5 cases indicate that the treatment is of value in this injury.

C. BACKGROUND

1. Decompression sickness is the formation of intra-vascular and extra-vascular gas bubbles as the result of inadequate or excessively fast decompression from pressure. It is most commonly seen in divers and caisson workers who return from pressures greater than atmospheric, but it has also been seen in aviators who ascend to pressures less than atmospheric. The severity and criticality of the resulting disability is related more to the anatomic lodgment of the bubble, which may press on nerves or obstruct blood supply to important areas, than to the magnitude of the missed decompression. Therapy for this condition aims to the relief of the injury by reduction in size or resolution of the bubble. This is achieved in the Navy standard Treatment Tables by recompression of the patient and his bubble to the maximum practical depth in a compression chamber followed by slow decompression to atmospheric pressure to forestall re-formation of bubbles in the already compromised circulation of the injured tissue. In these tables, which have been in use without important modification in the Navy for 20 years, the duration of the treatment varies from two to thirty-eight hours depending on the location or seriousness of the initial injury and on the patient's response to therapy.

2. The U. S. Navy Treatment Tables of reference (a) were adopted for use on a worldwide basis and achieved significant success for quite some time after their standardization. However, this success was chiefly with naval divers and was based on early diagnosis of injury and prompt recompression in chambers which were located at the site of diving operations. With the increase in diving as a recreation and pastime, and as more and more diving was done with SCUBA at sites distant from recompression chamber locations, naval facilities began to see and treat more patients who had delayed reporting for treatment until disability was extensive, serious, or fixed. Especially in those cases which have been delayed in treatment, the injury often persists after resolution of the bubble due to aggravation by vasospasm, ischemia, edema and thrombosis.

3. The breathing of pure oxygen was used in the Treatment Tables upon return to 60 feet to decrease the time required for decompression from that depth to the surface. This was made possible by acceleration of inert gas desaturation with increase of the pressure differential between the blood-tissue inert gas level and that of the alveolar gas. Another important effect, however, was the increase in oxygenation of injured and ischemic tissue distal to the original obstruction. Use of pure oxygen deeper than 60 feet was not feasible because of the risk of oxygen toxicity with greater oxygen pressure.

4. Several cases of decompression sickness were treated at the Experimental Diving Unit with a method which includes recompression to the maximum safe depth for breathing 100% oxygen, for a period of time sufficient to effect bubble resolution, followed by a moderately slow decompression also on oxygen. Initial results were so promising that permission was requested from the Surgeon-General for more extensive evaluation of this method at the Experimental Diving Unit, the Submarine Medical Center, and the Submarine Base Pear Harbor.

5. The objective of the method is to expose bubbles to the optimum pressure gradient for efficient and rapid resolution while still permitting maximum oxygenation of tissues with circulation impaired with bubbles. Oxygen here has the effect of preserving function in ischemic vital areas and also interrupting the invidious cycle of ischemia, hypoxia, edema, obstruction, and further ischemia. An important collateral benefit is the absence of further inert gas saturation of the patient under recompression with pure oxygen. Inert gas increase is an important consideration also in recompression therapy of aviators with persistent dysbarism since they commonly are partly denitrogenated even though suffering from bubble obstruction.

6. The volume of any spherical bubble decreases inversely with applied pressure. The Treatment Tables stop recompression at 165 feet gauge pressure because relative decrements of volume with increasing pressure become insignificant past 1/6 of the original bubble volume, while increasing the depth past 6 atmospheres absolute enormously increases the difficulties of subsequent decompression back to normal pressure, especially in an injured patient. The geometry of the situation, however, is such that the radius of the bubble decreases as the cube root of the applied pressure. The diminution of the radius, therefore, decreases at even shallower depths than 165 feet.

7. Bubble resolution in decompression sickness depends both on a reduction in size with recompression and on the elimination of inert gas from the bubble and from the surrounding tissue. In severely injured patients treated with recompression to 165 feet, inert gas exchange is grossly impaired in areas distal to obstruction. Bubbles may form during subsequent decompression in areas of tissue injury which have inadequate inert gas elimination rates due to circulatory impairment. The avoidance of further inert gas uptake by compressing only to 60 feet and the acceleration of inert gas elimination by oxygen breathing may overbalance any small decrease in bubble radius from further compression to 6 atmospheres. In patients for whom treatment has been delayed and in whom vascular obstruction from edema and thrombosis may be of an importance equal to or greater than that from persistent bubbles, the hyperbaric oxygenation given immediately in treatment is believed to be of substantially more benefit than increased bubble compression with compressed air breathing.

8. Reference (b) relates that, although there were no instances of clinical failure with treatment of Navy divers on Table 3 and 4, out of 62 civilians treated in a two year period with these tables 29 treatments terminated in a clinically unsatisfactory manner. It is these patients who will derive the greatest therapeutic benefit from application of the new treatment method. Navy divers will however receive equally beneficial treatment with a considerable saving in time required for treatment.

D. RESULTS AND DISCUSSION

1. Treatment of Decompression Sickness

a. Research Report 5-65. Appendix I of reference (b) tabulates 87 patients treated with a schedule of recompression and oxygen breathing. 31 cases of decompression sickness were reported from the RCAF Institute of Aviation Medicine and will be commented on in the next paragraph. A further 8 were cases of traumatic air embolism and 3 were cases of avator's dysbarism. Of the remaining 45 cases of decompression sickness, the treatment of 40 was successful on first recompression, 2 recovered completely with a second treatment, and 3 had some residual upon completion of treatment.

b. RCAF Institute of Aviation Medicine. The organization with the largest experience of this method of treatment is the RCAF Institute of Aviation Medicine in Toronto. With the kind cooperation of Surgeon Commander D. J. Kidd, Royal Canadian Navy, Officer in Charge of the RCN Personnel Research Unit there, 31 cases of decompression sickness from that Institute were included in reference (b) and tabulated in its Appendix I. An earlier schema was used (see page 3 of the report) in which recompression stopped at 33 feet if relief was accomplished there. 22 additional cases have been treated since then at the Institute. Nine cases showed central nervous system involvement; the remaining 44 involved pain alone or with skin symptoms. One patient found it impossible to breathe oxygen through a face mask and could not be treated with this method. His case has been excluded from consideration. 19 patients got relief at 33 feet and were not recompressed further. There were five recurrences, all treated successfully with one repetition of the treatment schedule. 100% of a total of 52 cases are therefore considered successful applications of this method.

c. This Report. 26 additional cases of decompression sickness are included in Table 1. Regardless of the particular schedule used, 18 patients achieved complete recovery with one treatment, 2 required one re-treatment for complete recovery, and 1 was not completely relieved until his third treatment. 1 patient obtained complete relief only by compression to 165 feet, after 90 minutes at 60 feet was insufficient for this purpose: a successful treatment but failure of the oxygen method. 4 patients received considerable improvement from their therapy but had residual defects at its end.

d. Totals. 123 cases of decompression sickness have been treated to date by this new method of recompression to shallow depth while breathing 100% oxygen. 105 patients were completely relieved of all defects after one treatment, 9 required only one additional treatment, and 1 was completely relieved of his symptoms after a third treatment. These totals represent an 85.4% initial and 93.5% overall success rate with this method of treatment.

e. Failures. Eight patients received less than complete relief of all symptoms and are adjudged failures of the methods. These cases are described briefly as follows:

(1) 017 (E6) Subject felt apprehensive and tremulous 4 1/2 hours following ascent from a long experimental dive. This was followed by transient episodes of dizziness. These symptoms abated during oxygen breathing on the surface but returned 10 minutes later. His symptoms were relieved promptly after recompression to 33 feet breathing oxygen. At 10 feet during ascent some feeling of apprehension returned. No objective signs of central nervous system involvement were evident. Return to 20 feet for a further 35 minutes cleared his apprehension and an uneventful return to the surface followed. On the following day some dizziness and apprehension returned. A trial of oxygen recompression gave subjective improvement at depth. It is considered that vestibular function impairment occurred and that some time was required for resolution to take place, rather than that gaseous bubbles persisted or recurred.

(2) 257 (P8) A 30 year old civilian diver developed severe abdominal pain with dizziness and numbness and weakness of both legs following the last of several dives to over 100 feet. 190 minutes later he was recompressed to 60 feet on oxygen. He received no benefit from either of two treatment on Table 6. The patient was apathetic throughout. It was difficult to test his actual muscle strength, and his legs possibly became weaker during treatment. He was hospitalized after completion of recompression. During his stay there he lost strength in his upper extremities as well, but this returned in the following two weeks. On his sixth day of hospitalization he become febrile and was treated for a right lower lobe pneumonia. A lumbar puncture was done that day and his spinal fluid protein was 105 mg. %.

(3) 290 (U5) A 40 year civilian diver worked for about 3 1/2 hours at 50 feet with 3 surfacings and a break for lunch. Thirty minutes after finishing work he experienced itching, intense pain in shoulders and elbows, dizziness, vertigo, nausea, and vomiting. He received relief of pain with treatment on Table 6, but his vertigo persisted even in the chamber. He was admitted to the hospital with nystagmus and vertigo. He was discharged six days later with only slight nystagmus and this had disappeared after seven more days.

(4) 275 (17) A recreational SCUBA diver made three dives to about 130 feet. Ten minutes after the last ascent he noted onset of severe pain in his left shoulder, arm, and leg, and then later developed moderate weakness of his left arm and leg. Treated with Table 6 four hours later, he had complete relief of symptoms in his left leg after 30 minutes and in his left arm after 130 minutes. He still had some residual soreness of his left biceps after surfacing which lessened during ten hours of observation. A day later he returned with the complaint that the pain had started to become worse again and that he now had numbness of his left shoulder and upper arm. Numbness was removed by retreatment but his pain was only partially relieved. The pain disappeared three days later after immobilization in a Velpeau bandage.

(5) 408 (19) A 30 year old civilian made three working dives to 130 feet. Five minutes later he experienced pain, weakness, and numbness of his right leg together with general malaise and lightheadedness. He treated himself twice with water recompression and then went home to bed. When examined at a compression facility 12 hours later he had a positive Romberg with falling to the right. There was marked weakness of the muscles of the right leg with moderate weakness on the left. The gait was wide based and ataxic. Upon recompression his pain disappeared and muscle strength returned. However, the staggering gait, positive Romberg, and numbness were unchanged and remained so throughout treatment. His Romberg became negative and his gait improved in the subsequent 36 hours with further improvement and disappearance of numbness in the following week.

(6) 435 (22) A 38 year old civilian made two working dives to 80 feet. Five minutes after surfacing he suffered severe cramping abdominal pain which lasted several minutes. Five minutes after pain onset he experienced numbness with paresthesias from his nipples down. He had difficulty urinating. After nine hours he developed weakness of his right leg. He was treated on a Table 6 20 hours after onset of first symptom. An immediate return of muscle strength was noted at 60 feet and this continued to improve throughout treatment. His numbness and paresthesia diminished. At completion he could walk with slight difficulty, his Romberg was positive, and there was still slight weakness, numbness, and paresthesia. In the next 24 hours the positive Romberg disappeared and his gait improved, muscle weakness diminished further, and almost all numbness was gone.

(7) 460 (24) Twenty minutes after surfacing from a long dive to 90 feet this 49 year old civilian diver experienced blurring of his vision and a tightness of his chest. He was then stricken with weakness and numbness of his legs, worse on the right. He vomited twice and noted that he could urinate only with difficulty. He was flown to a chamber facility the next day and treated on a Table 6. He noted some change in his right leg only after 75 minutes at 60 feet, and there was some further improvement during the rest of the treatment. At the completion of treatment his strength seemed equal in both legs and gait and balance were normal. He was able to void with minimal difficulty. There was still diminished sensation to pin-pick in his right lower leg.

(8) 500 (26) An 18 year old female SCUBA diver experienced severe frontal headache with radiation to the back of her neck at 50 feet while ascending from a 2 minute dive to 125 feet which had been her third dive in eight hours. On arriving at the surface she felt lightheaded, her pains became worse and she developed new pains in her stomach and right side of her neck. Water recompression gave no relief. She became nauseated and her vision blurred. She reported losing consciousness several time while traveling to a recompression facility. She received some relief of her pain at 60 feet but the pain in the back of her neck persisted and after 90 minutes the pains in her arms and shoulders returned. She was taken to 165 feet on compressed air and all pain was relieved. She was kept at 165 feet for 30 minutes, brought back to 60 feet over the next 30 minutes, and then decompressed to the surface on Table 6.

f. Omitted Decompression. Certain emergencies may interrupt or prevent specified decompression. Even without evidence of any ill effects, omitted decompression must be made up in some manner to avert later difficulty. The standard procedure is to recompress the diver to 100 feet and observe him for 30 minutes. If he is all right after that time, he is decompressed according to the schedule of Table 1 or Table 1A. Decompression sickness developing during or after this procedure is considered a recurrence. On theoretical grounds Table 5 is an adequate and sufficient substitute for Table 1 or 1A as a preventive measure following most episodes of omitted decompression. If a recompression chamber and facilities for oxygen administration are available, however, Table 1 would normally have been selected and the substitution of Table 5 gives little therapeutic or time-saving advantage. If the omitted decompression includes stops deeper than 60 feet or represents a degassing of such magnitude that bubble formation would be likely to take place at the hydrostatic pressure of 60 feet gauge depth, then the shallow depth oxygen breathing tables should not be used. A single, clear procedure for an emergency situation is to be preferred. It is felt that the current regulations should not be modified. The present procedure has applicability to a wider range of possible situations and the familiarity of long usage. If decompression sickness develops after the precautionary recompression, it is considered a recurrence and Table 6 may be used for treatment.

2. Treatment of Air Embolism

a. Eighteen cases of air embolism have been treated. Ten cases have been reported in addition to N1, N2, P2, P5, P10, R24, S1, and U1 of reference (b). Of these eighteen cases, six occurred during "routine" diving operations and twelve followed as a consequence of ascent training at the submarine escape training facilities at New London and at Pearl Harbor.

b. Air Embolism in Divers. Immediate treatment is essential when signs of central nervous system involvement are seen in a diver following exposure to increased pressure. The differential diagnosis between decompression sickness and air embolism is often not immediately apparent but must be made on the basis of conditions of the dive as well as by history and physical examination of the diver. In many cases the diagnosis is never certain but remains a considered judgment only. It is imperative, therefore, that the treatment given be adequate for either condition.

(1) An abstract of six cases of air embolism in divers is given in Table 2. Case R24, S1, and U1 are repeated from reference (b). Treatment of these three was successful with recompression to 33 feet (U1) or to 60 feet (R24 and S1). The patient of case 280 was relieved of his moderate symptoms of numbness and weakness by oxygen breathing on the surface for 15 minutes. Upon arrival at the chamber facility he was given further treatment on Table 6 as a precautionary measure. The treatment of the patient of case 401 was instituted within 45 minutes of his injury. His coma and extensive paralysis were unchanged after 6 minutes oxygen breathing at 60 feet, so he was compressed further to 165 feet. Considerable improvement was noted there, so he was given

30 minutes at that depth and then brought to 60 feet and put on the schedule of Table 6. 24 hours after treatment he had only minimal residual weakness and numbness of his right shoulder. The patient of case 471 experienced dizziness at his 10 foot decompression stop after a minimal air dive and then developed an increasingly severe right hemiplegia after surfacing. He was dramatically relieved of his paralysis during the descent to 60 feet and was treated on Table 6. This was subsequently discovered to be the third air embolism this man had suffered, and he was disqualified for further diving.

c. Submarine Escape Training. Buoyant ascent training for submarine personnel is a hazardous operation and it has been carefully supported with special staff and facilities to ensure safety. Air embolism can appear rapidly, abruptly, and catastrophically in trainees. The trainee is carefully watched at all times and treatment is initiated immediately symptoms appear. Inert gas uptake from pressure exposure is minimal in comparison to diving operations, there is little possibility of confusion with decompression sickness, and the problems with recompression to 165 feet as a repetitive dive are minimized. To reap the benefits of full bubble compression under these circumstances the Commanding Officer, Submarine Medical Center, has developed a treatment which begins with immediate recompression to 165 feet on air. The patient is maintained at this depth for a time and is then decompressed to 60 feet and given hyperbaric oxygenation on a schedule similar to that of Table 5. (Decompression from 60 minutes at 165 feet calls for an ascent at 60 feet per minute to a first stop at 50 feet. Ascents on this treatment have generally been at 25 feet per minute to 60 feet.)

(1) The twelve buoyant ascent cases have been tabulated in Table 3. Eleven were taken to 165 feet and kept there for a period ranging from 6 to 30 minutes. Only six had complete relief before leaving 165 feet, and two of these had a recurrence at 30 feet. One patient was taken back to 165 feet and successfully retreated on Table 4. The second was recompressed to 60 feet and successfully retreated on the schedule of Table 6. Of the five patients who were taken from 165 feet before they were completely relieved, all also recovered completely. The patient of case 423 was normal shortly after reaching 60 feet but his condition deteriorated after 75 minutes at that depth. He was accordingly kept at 60 feet for three hours breathing alternately oxygen and air. His treatment schedule thereafter was in accordance with Table 6 and he was noted to be completely recovered after treatment. The patient of case 501 was not taken to 165 feet. He recovered completely from a right arm paralysis and paralysis of right conjugate gaze immediately on reaching 60 feet and was therefore treated on Table 5. Treatment was successful.

(2) In this small series the initial success rate with treatment can be stated as only 75%. However, all patients recovered completely before the end of treatment, including treatment of recurrences. In case 060, one of the first in which this method was applied, the decision was made to treat the recurrence on Table 4 rather than Table 6 when a convulsion occurred. The patient had been brought up to 30 feet despite his complaints of increasing

nervousness, headache, nausea, and numbness. It is not clear whether his convulsion resulted from bubble recurrence or oxygen toxicity. He remained in a stuporous, possibly post-ictal, condition for 155 minutes after return to 165 feet.

(3) It is considered that the method outlined is the optimum approach to treatment of traumatic air embolism occurring under the conditions of ascent training at the submarine escape training facilities. Standardization of the exact schedule is deferred to the Submarine Medical Center.

3. Treatment of Altitude Bends in Aviation

a. In a few reported cases of aviator's dysbarism symptoms persisted despite a return to ground level. It is considered that in these cases the bubble formed by decompression to altitude was not completely resolved by recompression back to one atmosphere. From analogy to decompression sickness of divers some of these patients were treated with standard Treatment Tables and were benefited. The oxygen breathing recompression tables would seem of particular value in these cases. Due to the nature of the bubble's genesis it might be adequately handled by recompression to a lesser depth, especially when the patient breathes 100% oxygen. Most of the patients had been partially denitrogenated by oxygen breathing and by altitude exposure during flight, and the objectionable feature of significant nitrogen uptake in the patient taken to 165 feet on air is removed.

(1) Treatment in 5 cases of persistent dysbarism is detailed in Table 4. Limited experience validates the rationale of its use and indicates that for best results in serious cases treatment should not be delayed.

E. RECOMMENDATIONS

1. It is recommended that the Minimal Recompression Oxygen Breathing Treatment method be approved and authorized for use, under the supervision of appropriately trained medical officers, in the treatment of decompression sickness and air embolism. The two new treatment schedules would be in addition to the present six standard treatment schedules (Table 1, 1A. 2, 2A, 3, and 4) of Table 1-21 of the U. S. Navy Diving Manual (NAVSHIPS 250-538); and would be inserted and described as Treatment Tables 5 and 6 in the next revision of the U. S. Navy Diving Manual.

F. REFERENCES

(a) U. S. Navy Diving Manual (NAVSHIPS 250-538), Government Printing Office, Washington, D. C. 20402.

(b) Experimental Diving Unit Research Report 5-65, Minimal Recompression, Oxygen Breathing Approach to Treatment of Decompression Sickness in Divers and Aviators, M. W. GOODMAN and R. D. WORKMAN, 15 November 1965, Washington Navy Yard, Washington, D. C.

EXPLANATION OF TABLES AND INCLUDED ABBREVIATIONS FOR TABLES 1 THROUGH 4

All time is given in minutes only or in hours:minutes

Dive Denotes purpose of dive, number of dives, and identifies cases other than decompression sickness of divers.

A	Altitude exposure	R	Recreational dive
B	Buoyant ascent	W	Working dive
C	Civilian diver	2-5	Number of dives, if more than one
E	Experimental dive		

Mix Breathing mixture during exposure.

Max Depth or **Max Altitude** Greatest depth or altitude attained has been listed in cases with multilevel or repetitive exposures.

Total Bottom Time or **Time** Sums of individual bottom times have been listed in cases with repetitive dives. Time at greatest altitude is given for altitude exposures.

Ascent 1st or 2nd ascent of escape training cycle.

Pain, Neurological, Other

1	Minimal	M	Motor deficit	C	Convulsion
2	Mild	S	Sensory deficit	U	Unconsciousness
3	Moderate	SS	Special sense organ involvement (e.g. eye)	N	Nausea
4	Severe			V	Vomiting

Onset Symptoms Time from surfacing to appearance of first symptoms, or time from reaching altitude to appearance of first symptoms.

Onset Therapy Time from onset of first symptom to beginning of adequate therapy.

Onset Relief Time from beginning of adequate therapy to onset of complete relief.

Table
5 Table 5 Short oxygen treatment table
6 Table 6 Long oxygen treatment table
SMC Submarine Medical Center modification for treatment of air embolism.

Result
1 Relief complete
2 Residual deficit
4 Recurrent symptoms

TREATMENT OF DECOMPRESSION SICKNESS

— TABLE 1 —

CASE		EXPOSURE					SYNDROME			TREATMENT					REMARKS
EDU	NR	DIVE	AGE	MIX	MAX. DEPTH	TOTAL BOTT.TIME	PAIN	NEURO	OTHER	ONSET SYMP.	ONSET THERAPY	P. of F	TABLE	RESULT	
409	1	E	36	N_2 O_2	150	50	1	3M-S	—	P	5	7	5	1	
418	2A	CR3	33	AIR	170	33	4	4M-S-SS	—	1	20:00	71	6	4	VISUAL BLURRINESS CLEARED BEFORE RECOMPRESSION NORMAL WHEN TREATMENT COMPLETED.
418	2B						2	3M-S	—	4:06	1:12	20	5	1	RECURRENCE FOLLOWING TREATMENT. RE-TREATMENT COMPLETELY SUCCESSFUL.
436	3	E	36	N_2 O_2	150	60	4	—	—	4:50	25	2	5	1	
443	4	E	36	AIR	190	30	2	2M	—	50	4	1	6	1	
461	5	W	26	AIR	150	25	2	2M	—	29	1:42	1	5	1	
466	6	E	37	N_2 O_2	450	30	2	—	—	P	40	5	5	1	TREATMENT UNDER PRESSURE. RETURN FROM 14 TO 60 FEET AND SCHEDULE OF TABLE 5 BACK TO 14 FEET.
472	7	E	37	N_2 O_2	400	60	3	—	—	P	42	6	5	1	TREATMENT UNDER PRESSURE. RETURN FROM 44 TO 60 FT @ 70 MIN. INTERMITTENT OXYGEN BREATHING DURING ASCENT BACK TO 44 FEET.
475	8	E	38	N_2 O_2	200	24:00	2	—	—	P	3:03	5	5	1	
477	9	E	30	N_2 O_2	400	60	1	—	—	51	3	2	—	1	COMPLETE RELIEF WITH O_2 TREATMENT TO 33 FEET ONLY.
478	10	E	38	N_2 O_2	400	60	2	—	—	4:55	1:36	1	5	1	
480	11	CW5	35	AIR	125	130	4	3MS	—	20	25:30	1:30	5	1	
481	12	CR4	46	AIR	125	130	4	3M	—	5	4:17	1	5	1	
488	13	E	36	N_2 O_2	450	120	2	—	—	P	1:02	2	5	1	
492	14	E	29	N_2 O_2	450	27:31	2	—	—	P	15	5	5	4	PAIN RETURNED AT 40 FEET. DISAPPEARED AFTER RE-COMPRESSION TO 50 FEET.(1)
493	15	E	39	N_2 O_2	200	8:00	3	—	—	8:20	1:04	2	5	1	
229	16	W	26	AIR	244	7	3	4S	—	1:25	12	47	6	1	
275	17A	C-R-4	29	AIR	130	72	4	3M-S	—	10	4:53		6	4	HEMIPARESIS CURED, BUT HAD RESIDUAL MUSCLE SORENESS WHICH BECAME WORSE THE FOLLOWING DAY AND WAS ASSOCIATED WITH RECURRENT NUMBNESS.
275	17B						4	2S	—	10:00	33:00		6	2	RE-TREATMENT RELIEVED NUMBNESS. PAIN BETTER AND DISAPPEARED AFTER 3 DAYS.
403	18	E	30	AIR	80	110	4	2M	—	23	2:07	24	6	1	
408	19	CW5	30	AIR	130	30	3	3MS	N	5	12:00		6	2	RESIDUAL CEREBELLAR DYSFUNCTION IMPROVED DURING SUBSEQUENT WEEK IN HOSPITAL.
410	20	CW	36	AIR	200	11	4	2M-S	—	1	6:00	70	6	1	
420	21	W	25	AIR	90	22	—	3M-S	—	7	12	15	6	1	
435	22	C-2	38	AIR	80	40	4	4M-S	—	5	10:20		6	2	CONSIDERABLE IMPROVEMENT IN PERSISTENT NEUROLOGIC DEFICIT IN 24 HOURS AFTER COMPRESSION.
445	23	W	22	AIR	199	10	—	3S	—	1:38	8:40	50	5	1	
460	24	CW	49	AIR	75	90	3	2S-M-S	N:V	20	29:32		6	2	PERSISTENT DIMINISHED SENSATION IN ONE LEG AFTER TREATMENT. MODERATE PARAPARESIS RELIEVED.
482	25A	CW5	23	AIR	80	300	4	4M-S	—	10	11:00	2:00	6	4	SYMPTOMS COMPLETELY RELIEVED EXCEPT SLIGHT SHOULDER ACHE.
482	25B						4	3M	—	6:30	1:25	—	6	2	FIRST RECURRENCE. ALL SYMPTOMS RELIEVED AFTER RE-TREATMENT EXCEPT SLIGHT SHOULDER ACHE.
482	25C						1	—	—	—	89	2	6	1	THIRD TREATMENT. ALL SYMPTOMS RELIEVED.
500	26	C-3	18	AIR	130	26	4	U-S	—	P	3:00	1:30		1	RELIEF INCOMPLETE AFTER 30 MIN AT 60 FT. TAKEN TO 100 FT ON AIR AND COMPLETE RELIEF AT START OF 30 MIN PERIOD THERE. RETURNED TO 60 FT. & SECOND COMPLETED ON SCHEDULE OF TABLE 6

TREATMENT OF TRAUMATIC AIR EMBOLISM IN DIVERS

— TABLE 2 —

CASE		EXPOSURE					SYNDROME			TREATMENT					REMARKS
EDU	NR	DIVE	AGE	MIX	MAX. DEPTH	TOTAL BOTT. TIME	PAIN	NEURO	OTHER	ONSET SYMPTOMS	ONSET THERAPY	RELIEF	TABLE	RESULT	
—	R24	E	29	AIR	245	21	2	2S	—	P	—	—	6	1	
272	S1	E	30	AIR	66	17	—	4M	—	10	4	5	5	1	
061	U1	CR	21	AIR	20	90	2	4U	C-S	15	10:27	8	—	1	TREATMENT TO 33 FEET ONLY. PNEUMOTHORAX, MEDIASTINAL EMPHYSEMA
280	34	W	31	$He O_2$	150	10	—	3SM	—	2	60	—	6	1	SYMPTOMS RELIEVED WITH OXYGEN BREATHING ON THE SURFACE
401	35	CW2	50	AIR	90	35	4	4UM	—	1	45	—	SMC	2	RESIDUAL MINIMAL WEAKNESS AND NUMBNESS OF RIGHT SHOULDER.
471	36	W	34	AIR	150	6	—	4MS	—	P	38	27	6	1	THIRD AIR EMBOLISM IN THIS DIVER

TREATMENT OF TRAUMATIC AIR EMBOLISM IN SUBMARINE ESCAPE TRAINEES

— TABLE 3 —

CASE		EXPOSURE				SYNDROME			TREATMENT							REMARKS
EDU	NR	DIVE	AGE	DEPTH	ASCENT	PAIN	NEURO	OTHER	ONSET SYMP.	ONSET THERAPY	TABLE	TIME AT 165 FT.	RELIEF	DEPTH OF RELIEF	RESULT	
054	N1	B	18	50	1ST	—	U4M	—	0	1	SMC	27	8	165	1	MEDIASTINAL EMPHYSEMA
060	P2	B	20	50	1ST	—	U-C	—	0	3	SMC	30	30	165	4	RECURRENCE AT 30 FEET. RETREATED ON TABLE 4. (1)
248	N2	B	27	50	1ST	3	4SS-M-S	—	0	3	SMC	30	56	30	1	
249	P5	B	21	50	2ND	—	3M-S	—	0	1	SMC	30	20	165	1	
269	P10	B	27	130	1ST	—	C-4M	—	P	3	SMC	30	67	60	1	PNEUMOTHORAX, PNEUMOPERICARDIUM
423	27	B	20	50	1ST	—	U	—	0	1	SMC	30			4	DETERIORATION IMPROVED WITH OXYGEN BREATHING AT 60 FEET. COMPLETE RECOVERY. PNEUMOTHORAX. (1)
425	28	B	18	50	1ST	—	U	—	0	1	SMC	22	22	165	1	
426	29	B	21	50	2ND	—	U-3M	—	P	1	SMC	6	2	165	1	VERTIGO IN WATER
473	30	B	19	50	2ND	3	U-4M	—	0	1	SMC	17	38	60	1	PNEUMOPERICARDIUM. CHEST PAIN AFTER FIRST ASCENT NOT REPORTED
490	31	B	20	50	1ST	2	3S-M	—	10	14	SMC	9	2:00	30	1	
501	32	B	19	50	1ST	—	4M	—	0	3	S	—	1	60	1	
479	33	B	20	50	2ND	—	U4M-SS	—	0	1	SMC	30	15	165	4	NEUROLOGIC DETERIORATION AT 30 FEET. RETURN TO 60 FEET AND RE-TREATED. COMPLETE RECOVERY. PNEUMOTHORAX, MEDIASTINAL EMPHYSEMA, AND RUPTURED EARDRUMS. (1)

TREATMENT OF PERSISTENT DYSBARISM
— TABLE 4 —

CASE		EXPOSURE					SYNDROME			TREATMENT					REMARKS
EDU	NR	AGE	CATEGORY	MIX	MAXIMUM ALTITUDE	TIME	PAIN	NEURO	OTHER	ONSET SYMPTOMS	ONSET THERAPY	RELIEF	TABLE	RESULTS	
291	K1	45	A	O_2	30,000	83	—	4MS	CS	41	14:00	8:00	—	2	RECOMPRESSED TO 30 FEET. BACK TO FULL DUTY AFTER THREE DAYS.
053	U2	34	A	O_2	27,000	23	3M	4MU	CS	22	1:32	9	5	1	NEUROCIRCULATORY COLLAPSE
122	U4	23	A	O_2	18,000	7:00	3M	—	—	7:00	7:20	15	5	1	
451	37	25	A	O_2	43,000	—	2	—	—	—	48:00	7	5	1	FIRST SYMPTOMS 30 MINUTES AFTER ALTITUDE RUN COMPLETED.
502	38	23	A	O_2	35,000	2:25	—	SS-U	—	2:25	1:15	50	—	1	TREATMENT 45 MINUTES OXYGEN AT 33 FEET WITH 15 MINUTE ASCENT TO SURFACE.

APPENDIX A - PROPOSED REGULATIONS FOR USE OF THE MINIMAL RECOMPRESSION OXYGEN BREATHING METHOD (TABLE 5 AND TABLE 6) IN TREATMENT OF DECOMPRESSION SICKNESS AND AIR EMBOLISM

MINIMAL RECOMPRESSION, OXYGEN BREATHING TREATMENT METHOD

1. Approval for use. Preliminary evaluation of the minimal recompression, oxygen breathing therapy for decompression sickness and air embolism indicates that it is safe and effective, especially for some severe injuries in which treatment has been delayed and which have responded poorly in the past to the standard Treatment Tables (Table 1-21) of the U. S. Navy Diving Manual (NAVSHIPS 250-538). Approval has therefore been granted for use of these oxygen treatment tables as an alternate procedure in situations where a medical officer trained in the treatment of decompression sickness is available. The use of oxygen breathing without recompression is not approved in any situation except in case of an emergency, during transport to a compression chamber, or during an interim period while recompression facilities are being prepared for use.

2. Choice of Table. The procedure for use of the minimal recompression, oxygen breathing treatment is given in Figure 1. The short (135 minute) schedule of Table 5 is used for treatment of "pain only" bends if all pain is completely relieved within ten minutes after reaching 60 feet. The long (285 minute) schedule of Table 6 is used for treatment of cases with more serious symptoms, such as those of central nervous system involvement, for recurrence, or if pain is not completely resolved in the first ten minutes at 60 feet. If symptoms recur or if new symptoms appear during or after treatment on either table, the patient should again be compressed to 60 feet and treated thereafter in accordance with the schedule of Table 6.

3. Descent. The patient starts breathing 100% oxygen before compression begins. Normal descent rate is 25 feet per minute. A rapid descent is desirable if serious symptoms are present. If only pain is involved do not exceed rate tolerated by patient. Do not halt descent to verify a report of symptom relief. Descent time is not counted as time at 60 feet.

4. Ascent. Ascent is continuous at one foot per minute. Do not compensate for slowing of the rate by subsequent acceleration. Do compensate if the rate is exceeded. If necessary, halt ascent and hold depth while ventilating the chamber.

5. Relief not complete.

a. If the relief of all signs and symptoms is not complete after a reasonable period at 60 feet, the responsible medical officer will have to advise whether or not continued treatment at depth is desirable.

(1) If further treatment at depth is felt to be of value then:

(a) Table 6 can be lengthened by an additional 25 minutes at 60 feet (20 minutes oxygen and 5 minutes air), or an additional 75 minutes at 30 feet (15 minutes air and 60 minutes oxygen), or both.

(b) Or the patient can be recompressed to 165 feet and treated thereafter in accordance with Table 2, 2A, 3, or 4 as appropriate.

(2) If it is felt that maximum benefit of compression has been obtained, then further treatment at depth is not necessary. The patient should be decompressed according to the schedule of Table 6. He should be observed closely, and if deterioration or any adverse change in his condition is noted, he can be recompressed to 60 feet for retreatment on Table 6 or taken to 165 feet and treatment completed on the appropriate table of Table 1-21.

(3) If the problem is not bends, the patient can be decompressed according to the schedule of Table 5.

b. Before making a recommendation the responsible medical officer should carefully consider:

(1) The diagnosis and exact condition of the patient.

(2) The nature of any defect remaining.

(3) The diving schedule which precipitated his injury and the magnitude of the omitted decompression, if any.

(4) The time intervals elapsed between the end of the patient's last dive, the onset of injury, and the commencement of treatment.

(5) The circulo-pulmonary condition of the patient and the status of his inert gas exchange.

(6) The presence of other medical conditions which might complicate treatment or necessitate later transfer to a hospital.

(7) Adjuvant therapeutic measures which might be of benefit.

6. Tenders

a. A qualified tender must be in the chamber:

(1) If the patient has had any serious symptoms.

(2) Whenever the patient is breathing oxygen.

(3) When the patient needs observation or care for any reason.

PROPOSED

b. Both Table 5 and Table 6 provide adequate decompression for the air breathing tender who remains in the chamber throughout the entire treatment, if it is his first dive of the day. If the treatment involves a repetitive dive for the tender or if the schedule of Table 6 is lengthened, then the tender must breath 100% oxygen during the final 30 minute ascent from 30 feet to the surface. In some situations it is desirable to bring an attendant, such as the Medical Officer, back to the surface before the end of the treatment. If this ascent is made before the end of the stay at 60 feet, the decompression obligation can usually be determined simply by use of the standard air decompression table or the repetitive air decompression tables. If this can not be easily done, it is better to keep the attendant inside the chamber throughout the full treatment schedule rather than risk the problem of treating decompression sickness in a tender while the other patient already occupies the decompression chamber.

FIGURE 1

METHOD USED WHEN RELIEF OF PAIN IS COMPLETE WITHIN 10 MINUTES AT 60 FEET

TABLE 5

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL ELAPSED TIME (MINUTES)
60	20	O_2	20
60	5	AIR	25
60	20	O_2	45
60-30	30	O_2	75
30	5	AIR	80
30	20	O_2	100
30	5	AIR	105
30-0	30	O_2	135

OXYGEN TIME Commence O_2 breathing prior to descent. Descent time is not counted as time at 60 feet.

COMPRESSION Normal rate of descent is 25 feet per minute. If serious symptoms are present descend as rapidly as possible. If symptoms are of pain only do not exceed a rate tolerable to the patient.

DECOMPRESSION Ascent is continuous at 1 foot per minute. Do not compensate for slowing of the rate by subsequent acceleration. Do compensate if the rate is exceeded. If necessary, halt ascent and hold depth while ventilating the chamber.

INSIDE TENDER Tender routinely breathes chamber air. If the treatment schedule is lengthened or if the treatment constitutes a repetitive dive for the tender, he must breathe oxygen for the final 30 minutes of ascent from 30 feet to the surface.

SERIOUS SYMPTOMS Unconsciousness, convulsions, weakness or inability to use arms or legs, air embolism, any visual disturbances, dizziness, loss of speech or hearing, chokes, bends under pressure.

METHOD USED WHEN RELIEF OF PAIN IS NOT COMPLETE WITHIN 10 MINUTES AT 60 FEET OR SERIOUS SYMPTOMS ARE PRESENT

TABLE 6

DEPTH (FEET)	TIME (MINUTES)	BREATHING MEDIA	TOTAL ELAPSED TIME (MINUTES)
60	20	O_2	20
60	5	AIR	25
60	20	O_2	45
60	5	AIR	50
60	20	O_2	70
60	5	AIR	75
60-30	30	O_2	105
30	15	AIR	120
30	60	O_2	180
30	15	AIR	195
30	60	O_2	255
30-0	30	O_2	285

CHOICE OF TABLE If completeness of relief is doubtful after 10 minutes of oxygen breathing at 60 feet use Table 6.

RECURRENCE If symptoms recur or if new symptoms appear, return to 60 feet and re-treat the patient on Table 6.

LENGTHENED TREATMENT Table 6 can be lengthened by an additional 25 minutes at 60 feet (20 minutes O_2 - 5 minutes air) or an additional 75 minutes at 30 feet (15 minutes air - 60 minutes O_2) or both.

RELIEF NOT COMPLETE If relief is not complete at 60 feet, proceed with Table 6 and observe patient's condition closely for any change, lengthen the schedule if thought necessary, or compress to 165 feet and treat patient on Table 2, 2A, 3 or 4 as appropriate.

FIGURE 2.

OXYGEN ADMINISTRATION: RULES, ROUTINES, REACTIONS AND PRECAUTIONS

IF OXYGEN INTOLERANCE OCCURS OR IS ANTICIPATED

(A) HALT ASCENT; REMOVE MASK AT ONCE; MAINTAIN DEPTH CONSTANT;

(B) PROTECT A CONVULSING PATIENT FROM INJURY DUE TO VIOLENT CONTACT WITH FIXTURES, DECKPLATES OR HULL, BUT DO NOT FORCEFULLY OPPOSE CONVULSIVE MOVEMENTS;

(C) WITH A PADDED MOUTHBIT PROTECT THE TONGUE OF A CONVULSING PATIENT;

(D) FOR NON-CONVULSIVE REACTIONS, HAVE PATIENT HYPERVENTILATE - WITH CHAMBER AIR - FOR SEVERAL BREATHS;

(E) ADMINISTER SEDATIVE DRUGS UPON DIRECTION OF A MEDICAL OFFICER;

(F) 15 MINUTES AFTER THE REACTION HAS ENTIRELY SUBSIDED RESUME THE SCHEDULE AT THE POINT OF ITS INTERRUPTION;

(G) IF THE REACTION OCCURRED AT 60 FEET, ON THE 135 MINUTE SCHEDULE: UPON ARRIVAL AT 30 FEET SWITCH TO 285 MINUTE-SCHEDULE (15 MINUTES AIR - 60 MINUTES OXYGEN, 15 MINUTES AIR - 60 MINUTES OXYGEN);

OXYGEN REACTIONS - SYMPTOMS

TWITCHING (FASCICULATIONS OR TREMORS) OF FACIAL MUSCLES AND LIPS; NAUSEA; DIZZINESS AND VERTIGO; VOMITING; CONVULSIONS; ANXIETY, CONFUSION, RESTLESSNESS AND IRRITABILITY; MALAISE; DISTURBANCES OF VISION AND NARROWING OF VISUAL FIELDS; INCOORDINATION; TREMORS OF ARMS OR LEGS; NUMBNESS OR "TINGLING" OF FINGERS OR TOES; FAINTING; SPASMOTIC BREATHING;

OXYGEN ADMINISTRATION - PREPAREDNESS

(A) SUFFICIENT CYLINDER SUPPLY

(B) DEMAND VALVES OPERATIVE

(C) EMERGENCY KIT STOCKED

(D) TENDERS TRAINED TO MANAGE REACTIONS

(E) O_2 HUMIDIFIED IF POSSIBLE

(F) DEPTH GAUGES CURRENTLY IN CALIBRATION

OXYGEN ADMINISTRATION - ROUTINE PRACTICES

(A) INSURE PATIENT IS AS COMFORTABLE AS POSSIBLE

(B) PATIENT AT COMPLETE REST

(C) INSURE SNUG FACE-MASK FIT

(D) FOLLOW AIR - O_2 SCHEDULE CLOSELY

(E) BE ALERT FOR SIGNS OR SYMPTOMS OF REACTIONS

(F) PATIENT TO TAKE A FEW DEEP BREATHS EVERY FIVE MINUTES DURING TREATMENT

FIRE WARNING

DANGER OF IGNITION AND PROPAGATION OF FIRE INCREASED UNDER PRESSURE AS O_2 IS EXHALED INTO THE CHAMBER ATMOSPHERE THE HAZARD IS MAGNIFIED. AMPLE VENTILATION MUST BE PROVIDED. DO NOT USE ELECTRICAL APPLIANCES. KEEP COMBUSTIBLES CLEAR OF THE CHAMBER.

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123 cases of decompression sickness, 18 cases of air embolism, and 5 cases of persistent dysbarism have been treated with a new method of recompression to 60 feet breathing 100% oxygen ~~(Table 5 and Table 6)~~. Results of treatment are discussed. Wider use of treatment method is recommended.

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